Micro-Doppler analysis of a vibrating/rotating target in TerraSAR-X images

T. Thayaparan, K. Mattar and D. Schlingmeier
DRDC, Ottawa Research Centre

Defence Research and Development Canada

Scientific Report
DRDC-RDDC-2014-R5
February 2014

Micro-Doppler analysis of a vibrating/rotating target in TerraSAR-X images

T. Thayaparan, K. Mattar and D. Schlingmeier
DRDC, Ottawa Research Centre

Defence Research and Development Canada
Scientific Report
DRDC-RDDC-2014-R5
February 2014

© Her Majesty the Queen in Right of Canada, as represented by the Minister of National Defence, 2014

© Sa Majesté la Reine (en droit du Canada), telle que représentée par le ministre de la Défense nationale, 2014

Abstract

The current search and rescue (S&R) methods consist of using signals in the visible spectrum to draw the observers' attention on board overflying S&R aircraft. These existing methods have proven useful but they have inherent limitations such as the requirement for daylight, good weather and relatively restricted areas of operations, due to aircraft range, observers' fatigue and field of view, as well as the low altitudes required for a thorough search. The Canadian Forces Joint Imagery Centre (CFJIC), Advanced Exploitation Section (AES) and DRDC, Ottawa Research Centre conducted an imagery experiment at Connaught Range to define alternate methods of detecting downed aircrew using space-based sensors such as RADARSAT-2 and TerraSAR-X. Preliminary results demonstrate that the signal-to-noise ratio (SNR) of the target signature is significantly enhanced when the data are analyzed through phase-amplitude comparison of the synthetic aperture radar (SAR) image. These results suggest that the utility of exploiting the unique phase signature of a moving reflector and pendulum for S&R purposes can potentially be useful in designs for emergency gear.

Significance to defence and security

The Canadian Forces Joint Imagery Centre (CFJIC), Advanced Exploitation Section (AES) and DRDC, Ottawa Research Centre conducted an imagery experiment called "Spring 2011 makeshift radar reflector trial" for search & rescue (S&R) purposes at Connaught Range in May 2011. The aim of the experiment was to define alternate methods of detecting downed aircrew, using space-based sensors. Some of the conclusions from CFJIC were that, due to the limitations of electro-optical sensors (IR), to weather and coarser resolution, the sensor of choice for the project was to be synthetic aperture radar (SAR)—to locate downed military aircrew in a combat environment. The current S&R methods consist in using signals in the visible spectrum, such as brightly coloured banners and signal fires to draw the observers' attention on board overflying S&R aircraft. These existing methods have proven useful but they have inherent limitations, such as the requirement for daylight, good weather and relatively restricted areas of operations, due to aircraft range, observers' fatigue and field of view, as well as the low altitudes required for a thorough search.

RADARSAT-2 and TerraSAR-X sensors were used to collect imagery during this experiment. Radar moving reflector (RMR) trials were conducted during this experiment. The peculiar aspect of the moving reflector and pendulum portion of the experiments are their potentially unique phase signature. The expected result was the creation of displacement streaks in the azimuth direction during the imagery operations. The presence of motion streak was observed in TerraSAR-X. Preliminary results indicate that the motion streak was not observed in RADARSAT-2 because of the short integration time. However, the data from TerraSAR-X were analyzed and it was successfully demonstrated that exploiting the unique phase signature of a moving reflector and pendulum for S&R purposes can potentially be useful in designs for emergency gear. It was also demonstrated that the signal-to-noise ratio (SNR) of the target signature is significantly enhanced when the data are analyzed through phase compared with the amplitude of the SAR image.

The use of spaced-based SAR has proven that producing a few constructed structures from materials that could be found in rescue kits and on the terrain would help improve the chances of detection and help reduce the overall search area. This sensor's ability to operate day and night and in all weather conditions would complement the current technology compared with the traditional search methods.

Résumé

Les méthodes actuelles de recherche et sauvetage (R-S) comportent l'utilisation de signaux dans le spectre visible pour attirer l'attention des observateurs à bord d'un aéronef de R-S en survol. Ces méthodes se sont révélées utiles, mais elles ont des limites inhérentes, comme la nécessité d'effectuer les opérations à la lumière du jour par beau temps et l'étendue relativement restreinte des zones d'opérations en raison du rayon d'action de l'aéronef, de la fatigue et du champ de vision des observateurs, ainsi que de la basse altitude exigée pour effectuer une recherche minutieuse. Le Centre d'imagerie interarmées des Forces canadiennes (CIIFC), la Section de l'exploitation avancée (SEA) et le Centre de recherches de RDDC Ottawa ont procédé à une expérience d'imagerie au Polygone de Connaught pour définir d'autres méthodes de détection d'équipages d'aéronefs tombés au moyen de capteurs spatiaux, comme RADARSAT-2 et TerraSAR-X. Selon les résultats préliminaires, le rapport signal/bruit (S/B) de la signature de la cible est largement accru lorsque les données sont analysées au moyen d'une comparaison phase-amplitude de l'image du radar à synthèse d'ouverture (RSO). Ces résultats suggèrent que l'exploitation de la signature de phase unique d'un réflecteur et d'un pendule en mouvement à des fins de R-S pourrait servir à la conception de matériel d'urgence.

Importance pour la défense et la sécurité

Le Centre d'imagerie interarmées des Forces canadiennes (CIIFC), la Section de l'exploitation avancée (SEA) et le Centre de recherches de RDDC Ottawa ont procédé, en mai 2011,à une expérience d'imagerie appelée *Spring 2011 makeshift radar reflector trial* (essai de réflecteurs radar improvisés au printemps 2011), à des fins de recherche et sauvetage (R-S). L'expérience vise à définir d'autres méthodes de détection d'équipages d'aéronefs tombés au moyen de capteurs spatiaux. Le CIIFC conclut notamment qu'en raison des limites des capteurs électro-optiques (IR) liées aux conditions météorologiques et à leur résolution grossière, le radar à synthèse d'ouverture (RSO) devrait être le capteur privilégié du projet pour localiser un équipage d'aéronef militaire abattu dans un environnement de combat. Les méthodes actuelles de R-S comportent l'utilisation de signaux dans le spectre visible, comme des bannières de couleurs voyantes et des feux de détresse, pour attirer l'attention des observateurs à bord d'un aéronef de R-S en survol. Ces méthodes se sont révélées utiles, mais elles ont des limites inhérentes, comme la nécessité d'effectuer les opérations à la lumière du jour par beau temps et l'étendue relativement restreinte des zones d'opérations en raison du rayon d'action de l'aéronef, de la fatigue et du champ de vision des observateurs, ainsi que de la basse altitude exigée pour effectuer une recherche minutieuse.

Pendant l'expérience, les capteurs RADARSAT-2 et TerraSAR-X sont utilisés pour recueillir des images. Des essais sont aussi réalisés avec des réflecteurs mobiles de radar (RMR). L'aspect particulier du réflecteur et du pendule mobiles de l'expérience est leur signature de phase potentiellement unique. Le résultat attendu est la création de traînées de mouvement dans la direction azimutale pendant les opérations d'imagerie. La présence de traînées de mouvement est observée dans les images prises par TerraSAR-X. Selon les résultats préliminaires, aucune traînée de mouvement n'est observée dans les images prises par RADARSAT-2 en raison du court délai

d’intégration. Toutefois, les données tirées de TerraSAR-X ont été analysées et ont permis de démontrer que l’exploitation de la signature de phase unique d’un réflecteur et d’un pendule mobiles aux fins de R-S pourrait servir à la conception de matériel d’urgence. Il s’avère également que le rapport signal/bruit (S/B) de la signature de la cible est largement accru lorsque les données sont analysées au moyen d’une comparaison phase-amplitude de l’image du RSO.

L’utilisation d’un RSO aérospatial démontre que la production de quelques structures construites à partir de matériaux provenant des trousses de sauvetage et du terrain aiderait à améliorer les chances de détection et à réduire la superficie totale de la zone de recherche. La capacité des capteurs à fonctionner de jour et de nuit dans toutes les conditions météorologiques compléterait la technologie actuelle par rapport aux méthodes traditionnelles de recherche.

Table of contents

List of figures

Acknowledgements

The authors would like to thank G. Duff and D. Lamothe for the support during the trial. The authors extend their gratitude to German Aerospace Centre (DLR) for the opportunity to collect TerraSAR-X data. TerraSAR-X data c DLR 2011.

This page intentionally left blank.

1 Introduction

Synthetic aperture radar (SAR) systems usually produce two-dimensional images. One dimension is called the range and is obtained by precisely measuring the time from transmission of a signal to its return. The second dimension is known as the azimuth and is perpendicular to the range dimension. The azimuthal resolution is obtained by processing the Doppler phase of the radar return. What differentiates SAR from other radars is its ability to produce fine azimuth resolution [1–6].

SAR is a well-established and useful technique of acquiring high-resolution images of an area of interest from airborne or space sensors [1, 2]. A particular class of targets that pose a difficult challenge for target recognition is moving targets. If there are moving targets in the scene, SAR cannot simultaneously produce clear images of both of these stationary targets and moving targets [3–6]. Usually, moving targets appear as defocused and spatially displaced objects superimposed on the SAR map. Moving targets cause phase modulation of the azimuth phase history of an SAR collection. The phase modulation can be seen as a time-varying Doppler frequency. It is obvious that in some scenarios it is the moving objects that are of interest. Some targets contain parts that move relative to the target itself. Examples are rotating antenna, swinging pendulum, rotating/vibrating parts such as wheels or engines, etc. Rotations and vibrations can be observed by radar when the conditions are right. The phenomenon, as observed by radar, is termed micro-Doppler (m-D). In addition to the m-D, there may be a Doppler shift corresponding to the target body motion.

The Canadian Forces Joint Imagery Centre (CFJIC), Advanced Exploitation Section (AES) and DRDC, Ottawa Research Centre conducted an imagery experiment named "Spring 2011 makeshift radar reflector trial" for search & rescue (S&R) purposes at Connaught Range in May 2011. The aim of the experiment was to define alternate methods of detecting downed aircrew, using space-based sensors. Some of the conclusions from CFJIC were that due to the limitations of electro optical sensors (IR), due to weather and coarser resolution, the sensor of choice for the project was to be SAR—to locate downed military aircrew in a combat environment. The current S&R methods consist of using signals in the visible spectrum, such as brightly colored banners and signal fires to attract the attention of observers within overflying S&R aircraft. These existing methods have proven useful but have inherent limitations such as the requirement for daylight, good weather and relatively restricted areas of operations, due to aircraft range, observer fatigue and the field of view, due to the low altitudes required for a thorough search.

Radar moving reflector (RMR) trials were conducted under the "Spring 2011 makeshift radar reflector trial" for S&R purposes and results demonstrate that the utility of exploiting the unique phase signature of a moving reflector and pendulum for S&R purposes can potentially be useful in designs for emergency gear. Traditionally, the target signature is analyzed through the magnitude of the SAR image. After investigating several approaches, it is demonstrated and established that the SNR of the target signature is significantly improved when the data is analyzed via phase compared to the magnitude of the SAR image. In Section 2, the m-D analysis is given. Results are presented in Section 3 and conclusions are given in Section 4.

2 Micro-Doppler analysis

The micro-Doppler (m-D) effect appears in the synthetic aperture radar (SAR) imaging when a target has one or more fast moving parts [8, 9, 14–16]. Similar effect appears in the inverse synthetic aperture radar (ISAR) imaging, as well, [7, 8, 13, 16]. This effect may decrease the readability of radar images. The frequency content of the m-D signal changes over time in a wide range. Therefore, the m-D may cover the rigid body and make it difficult to detect. On the other hand, the m-D effect, at the same time, carries useful information about the features of moving parts (type, velocity, size, etc.) [10]. It is easier to estimate these features if the m-D effect is separated from the rigid body part of the radar image. Thus, the extraction of m-D effects from the radar images has attracted significant research attention.

High-resolution linear and quadratic time-frequency (TF) analysis techniques have been used for extracting the m-D features [7–19, 21]. In [9], TF signatures of oscillating corner reflector are obtained by using an adaptive optimal kernel in distributions from the Cohen's class. The wavelet analysis of helicopter and human data, along with the TF representation based imaging system, is used in [11, 12, 14, 15]. A method for separating the m-D effect from the radar image, based on the chirplet transform, has been proposed in [13–15]. Both wavelet-based and chirplet-based procedures are used in [13] to extract the m-D parameters, such as the rotating frequency of an antenna in the SAR data. However, the effectiveness of the chirplet-based methods is dependent on the selection of the number of chirplets used in decomposition. Its calculation burden is also high, since the chirplet dictionary could be extremely large. Recently, two additional techniques for the target's rigid body separation from the m-D parts have been proposed in [16, 17]. The first technique is based on the order statistics of the spectrogram samples. The second one is based on the inverse Radon transform processing of the obtained radar signals. An efficient TF based approach, in conjunction with the Viterbi algorithm, is proposed in [19, 20] for the extraction of the m-D features.

In this report, we use the L-statistics based approach for the rigid body separation. In order to remove the m-D effect, we perform the TF analysis within the coherent integration time (CIT). In our previous approach [16, 17], we used order statistics and several TF representations with various windows. The obtained TF representations were then used to make decision whether a component belongs to the rigid body or to the fast moving target point. Here, we use only one window function in the analysis. Order statistics is performed based on the spectrogram, while the rigid body signal synthesis is done in the complex TF domain. This approach is very simple to use and produces better results than the other approaches. It is also robust to the noise influence, since it uses the L-statistics, being known as a robust signal processing tool [20]. The L-statistics application to the complex short-time Fourier transform (STFT) leads to a form of super-resolution representation, as well. It can separate very close rigid body components, even when that is not possible by using the standard Fourier transform (FT) over the entire CIT [21].

It should be noted that the rigid body and the fast moving points behave differently in the TF representation of the returned radar signal, within the CIT. The rigid body signal is almost constant in time (stationary), while the fast-varying m-D part of the signal is highly non-stationary. This part of the signal keeps changing its position in the frequency direction.

The basic idea for separating the rigid body and the fast rotating part is in the sorting of STFT values of the returned radar signal along the time axis, within the CIT. Since the rigid body return is stationary, the sorting procedure will not significantly change the distribution of its values. However, the fast-varying m-D part of the signal is highly non-stationary, occupying different

frequency bins for different time instants (in the case of flashes it exists for some time-instants only). Its existence is short in time, for each frequency, over a wide range of frequencies. Thus, after sorting the STFT along the time axis, the m-D part of the signal has strong values over a wide frequency range, but for a few samples only. By removing several large amplitude values of the sorted STFT, for each frequency, we eliminate most or all of the m-D part of the signal. Summing the rest of the STFT values over time we will get the rigid body radar image. The m-D part can be further analyzed to extract motion parameters that are complementary to existing target recognition methods [10]. The schematic diagram of the proposed method is given in Figure 1. A detailed description of this approach is given [21].

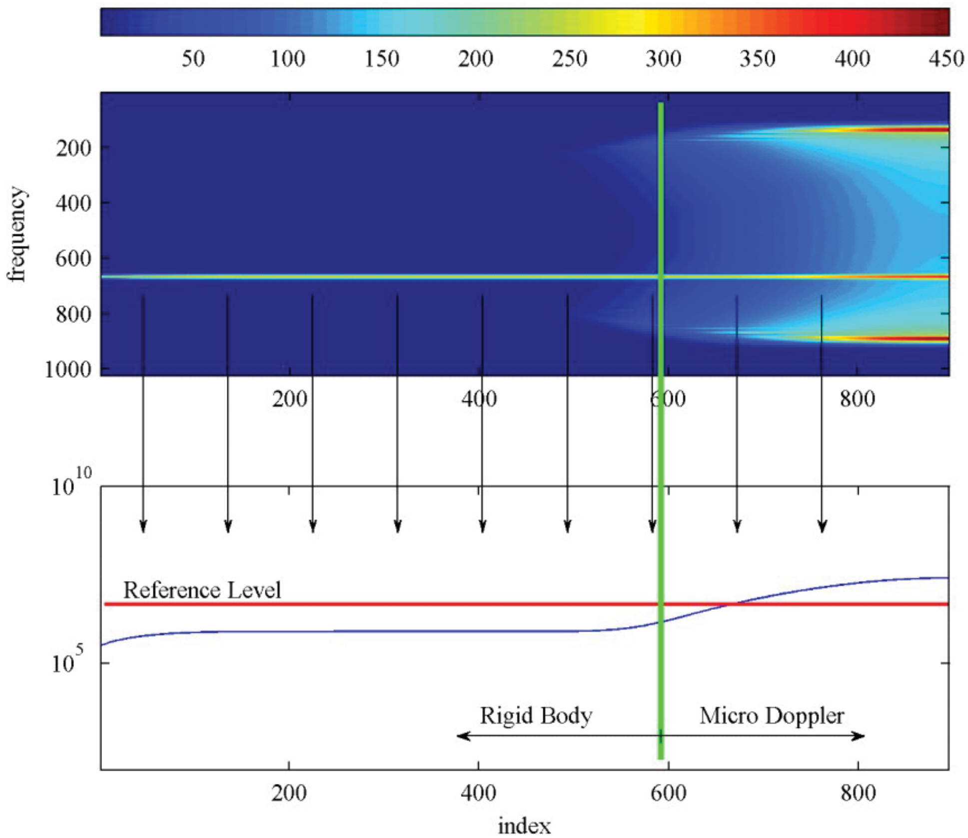

Figure 1*: Sorted STFT values with a color bar (upper). Amplitudes are obtained by summing the squared values of the sorted STFT along the frequency (lower). The reference level is obtained based on the average value of 10% of its smallest values—thick red horizontal line (lower).*

3 Results

3.1 Simulated data

The proposed method is tested on a signal with one rigid body point and four sinusoidally modulated components (used to model rotating reflectors),

$$s(m) = \sigma_B \sum_{i=1}^{K} \exp\{j y_{Bi} m\} \tag{1}$$

$$+\sigma_R \sum_{i=1}^{P} \exp\{j[y_{R0i} m + A_{Ri} \sin(\omega_{Ri} m + \theta_i)]\},$$

with $K = 1$, $P = 4$, $\sigma_B = 1$, $\sigma_R = 3$, $y_{B1} = 0.4\pi$, $A_{Ri} = [96, 48, 64, 24]$, $\omega_{Ri} = \pi/128$, $y_{R0i} = \pi$ and $\theta_i = 0$, for $i = 1, 2, 3, 4$. The STFT of this signal is presented in Figure 2a. The m-D, although moderate, significantly covers the rigid body, i.e., the part of the constant frequency component is almost invisible in the sinusoidal patterns. The sorted STFT is shown in Figure 2b. The original FT of the analyzed signal is given in Figure 2c. The FT reconstructed from the remaining STFT samples is shown in Figure 2d. The rigid body is successfully reconstructed in the presence of the m-D.

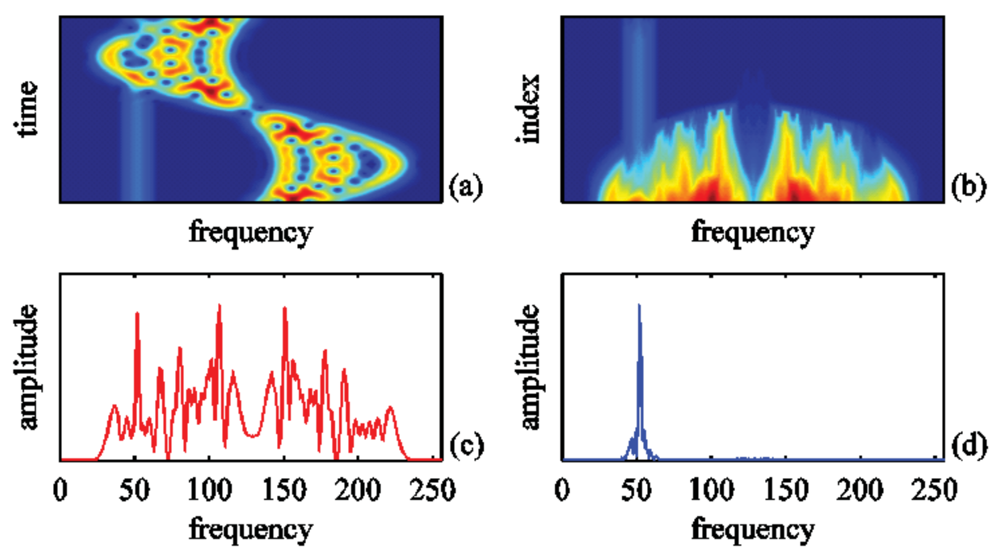

Figure 2: *(a) The STFT of a signal consisted of one rigid body component and four sinusoidally modulated components, (b) The sorted STFT of the same signal, (c) The original FT of the signal, and (d) The FT of rigid body, reconstructed by summing the STFT values remained after sorting and eliminating samples that correspond to the m-D effect.*

We now analyze a signal with 10 components: five components with constant frequency (used to model rigid body reflectors) and five sinusoidally modulated components (used to model rotating reflectors), Equation (1) with: $\sigma_B = 1$, $\sigma_R = 15$, $y_{Bi} = [1.9\pi,\ 1.95\pi,\ 2\pi,\ 2.05\pi,\ 2.1\pi]$, $A_{Ri} = [150, 300, 200, 440, 200]$, $\omega_{Ri} = [\pi/256,\ \pi/512,\ \pi/256,\ \pi/512,\ \pi/256]$, $y_{R0i} = 0$ and $\theta_i = [0\ ,\ -\pi/3,\ \pi/6,\ -2\pi/3,\ 0]$, for $i = 1, 2, 3, 4, 5$, $M = 1024$ and $M_w = 64$, where M is the total number of points and M_w is the window width. The STFT of this signal is shown in Figure 3a. The constant components, which correspond to the rigid body, are not well separated in the TF plane. Moreover, they are covered by the sinusoidally modulated patterns which represent the m-D effects of the rotating reflectors. If we sort the STFT values along the time axis, then the representation of the rigid body parts does not change, since it is constant during the whole CIT, Figure 3b. On the other hand, the fast rotating parts occupy only a small time interval over a wide region of frequencies. They lie in high value regions of the sorted transform. Thus, they will be eliminated by removing the highest STFT values, for each frequency. The reconstructed FT, obtained by summing the rest of the STFT along the time is shown in Figure 3d. We can clearly see five peaks that correspond to the five rigid body reflectors. The original FT is shown in Figure 3c. It cannot be used even to determine the number of components in the analyzed signal.

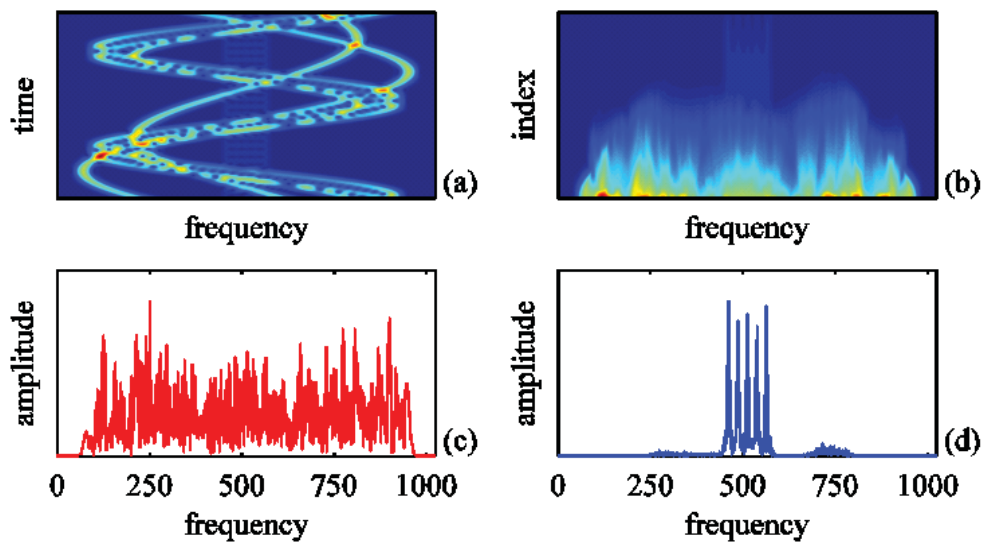

Figure 3: *The STFT of a signal consisted of five rigid body components and five sinusoidally modulated m-D components, (b) The sorted STFT of the same signal, (c) The original FT of the signal, and (d) The FT of rigid body, reconstructed by summing the STFT values remained after sorting and eliminating samples that correspond to the m-D effect.*

3.2 Measured data

Contrary to simulated data presented in the previous section, non-stationary parts are further analyzed to extract possible m-D features after removing the rigid body reflectors in this section.

Multi-space-based sensors such as RADARSAT-2 and TerraSAR-X were used to collect imagery during this experiment. The radar moving reflector was used in this trial. The proposed approach was used to extract the m-D features of the moving pendulum from the SAR image collected by TerraSAR-X. Figure 4 illustrates the creation of displacement streaks in the azimuth direction during the imagery operations. Figure 4a shows the SAR image and Figure 4b shows the zoomed image around the moving pendulum, which is located at range cell 568. After removing the rigid body reflectors from the data, the The STFT is used to extract the m-D feature of the moving pendulum at range cell 568. Figure 4c shows the resultant image of the moving pendulum in the time-frequency plane. The S-method is then used to improve the SNR of the image [18, 19]. Figure 4d shows the image enhancement of the moving pendulum. These results successfully demonstrated that the utility of exploiting the unique phase signature of a moving pendulum for S&R purposes, can potentially be useful in designs for emergency gear. The results also demonstrate that the SNR of the target signature is significantly enhanced when the data is analyzed via phase compared to the magnitude of the SAR image.

Figure 4b clearly shows presence of motion streak in TerraSAR-X. Preliminary results indicate that the motion streak is not observed in RADARSAT-2 because of the short integration time. Further analysis is needed to extract the displacement streak in the azimuth direction.

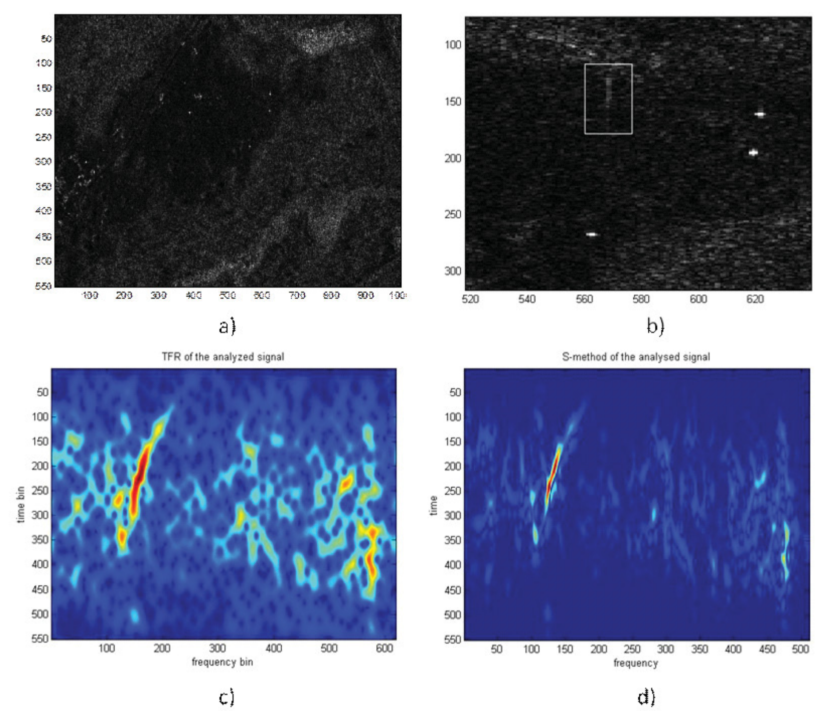

Figure 4: *a) SAR image, b) zoomed image around the pendulum, c) STFT at range cell 568 after removing the rigid parts, and d) s-method at range cell 568 after removing the rigid parts.*

4 Conclusion

The Canadian Forces Joint Imagery Centre (CFJIC), Advanced Exploitation Section (AES), and DRDC, Ottawa Research Centre conducted "Spring 2011 makeshift radar reflector trial" at Connaught Range in May 2011, an imagery experiment for search and rescue (S&R) purposes. The aim of the experiment was to define alternate methods of detecting downed aircrew, using space-based sensors. RADARSAT-2 and TerraSAR-X sensors were used to collect imagery during this experiment.

Traditionally, the target signature is analyzed through the magnitude of the SAR image. In this study, it was demonstrated that the SNR of the target signature is significantly improved when the data is analyzed via phase compared to the magnitude of the SAR image. The approach based on L-statistics in conjunction with the time-frequency analysis is used in this study. This approach is robust to the noise influence and clutter environments. Through the simulated and measured data, it is shown that the proposed approach successfully separates the rigid body and the m-D effects.

This page intentionally left blank.

References

[1] Oliver, C. and Quegan, S. (1998). Understanding synthetic aperture radar images, Artech House, Boston.

[2] Fransceschetti, G. and Lanari, R. (1999). Synthetic aperture radar processing, CRC press LLC, Boca Raton.

[3] Curlander, J. C. and McDonough, R. N. (1991). Synthetic aperture radar - system and signal processing, Wiley and Sons, New York.

[4] Carrara, W. G., Goodman, R. S., and Majewski, R. M. (1995). Spotlight synthetic aperture radar - signal processing alogorithm, Artech House, Norwood, MA.

[5] Wehner, D. (1995). High-resolution radar, Artech House, Norwood, MA.

[6] Soumekh, M. (1999). Synthetic aperture radar signal processing with Matlab algorithms, Wiley and Sons, New York.

[7] L. Stankovi´c, M. Dakovi´c and T. Thayaparan, Time-Frequency Signal Analysis With Applications, Artech House, Boston, 2013.

[8] Chen, V.C. and Ling, H. (2002). Time-Frequency transform for radar imaging and signal analysis, Artech House, Boston.

[9] T. Sparr, B. Krane: "Micro-Doppler analysis of vibrating targets in SAR,' IEE Proc. Radar Sonar Navig., Vol. 150, no. 4, pp. 277-283, Aug. 2003.

[10] Thayaparan, T., Abrol, S. and Riseborough, E. (2004). Micro-Doppler radar signatures for intelligent target recognition, DRDC Ottawa TM 2004-170.

[11] T. Thayaparan, S. Abrol, and E. Riseborough: "Micro-Doppler feature extraction of experimental helicopter data using wavelet and time frequency analysis,' RADAR 2004, Proc. of the International Conference on Radar Systems, 2004.

[12] T. Thayaparan, S. Abrol, E. Riseborough, L. Stankovi'c, D. Lamothe and G. Duff: "Analysis of radar micro-Doppler signatures from experimental helicopter and human data,", IET Proceedings Radar Sonar Navig., Vol. 1, no. 4, pp. 288-299, Aug. 2007.

[13] J. Li, and H. Ling: "Application of adaptive chirplet representation for ISAR feature extraction from targets with rotating parts,' IEE Proc. Radar, Sonar, Navig., Vol.150, No.4, pp.284-291, August 2003.

[14] T. Thayaparan, P. Suresh and S. Qian: "Micro-Doppler Analysis of Rotating Target in SAR, IET Signal Processing,' IET Signal Processing, Vol. 4, No. 3, pp 245-255, 2010.

[15] Thayaparan, T. and Abrol, S. (2005) Micro-Doppler Analysis of Rotating Target in SAR, DRDC Ottawa TM 2005-204, December 2005.

[16] Thayaparan, T. (2006) Separation of target rigid body and micro-Doppler effects in ISAR/SAR, DRDC Ottawa, TM 2006-187.

[17] L. Stankovi’c, T. Thayaparan, and I. Djurovi’c, “Separation of target rigid body and micro-Doppler effects in ISAR imaging”, IEEE Trans. Aerosp. Electron. Syst., Vol. 41, No. 4. pp. 1496-1506, Oct. 2006.

[18] T. Thayaparan, L. Stankovi’c and I. Djurovi’c: “Micro-Doppler Based Target Detection and Feature Extraction in Indoor and Outdoor Environments,’ J. of the Franklin Institute, Vol. 345, No. 6, pp 700-722, Sept. 2008.

[19] Thayaparan, T., Stankovic, LJ, and Djorovic, I. (2007). Target Detection and Feature Extraction in Indoor and Outdoor Environments using micro-Doppler analysis, DRDC Ottawa, TM 2008-255, 33 pages.

[20] I. Djurovi’c, L. Stankovi’c, J. F. Bohme: “Robust L-estimation based forms of signal transforms and time-frequency representations,’ IEEE Trans. Signal Processing, Vol. 51, No. 7, pp. 1753 - 1761, July 2003.

[21] L. Stankovi´c, T. Thayaparan, M. Dakovi´c, and V. Popovi´c-Bugarin, “Micro-Doppler removal in the radar imaging analysis,” IEEE Trans. on Aerospace and Electronics Systems, Vol. 49, No. 2, Apr. 2013, pp. 1234-1250.

DOCUMENT CONTROL DATA

(Security markings for the title, abstract and indexing annotation must be entered when the document is Classified or Designated)

1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g., Centre sponsoring a contractor's report, or tasking agency, are entered in Section 8.) DRDC – Ottawa Research Centre 3701 Carling Avenue Ottawa, Ontario K1A 0Z4	2a. SECURITY MARKING (Overall security marking of the document including special supplemental markings if applicable.) UNCLASSIFIED 2b. CONTROLLED GOODS (NON-CONTROLLED GOODS) DMC A REVIEW: GCEC APRIL 2011

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

Micro-Doppler analysis of a vibrating/rotating target in TerraSAR-X images

4. AUTHORS (last name, followed by initials – ranks, titles, etc., not to be used)

Thayaparan, T; Mattar, K.; Schlingmeier, D.

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
February 2014	22	21

7. DESCRIPTIVE NOTES (The category of the document, e.g., technical report, technical note or memorandum. If appropriate, enter the type of report, e.g., interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Scientific Report

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

DRDC – Ottawa Research Centre
3701 Carling Avenue
Ottawa, Ontario K1A 0Z4

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
15dp	
10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)
DRDC-RDDC-2014-R5	

11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification.)

Unlimited

12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.))

Unlimited

13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

The current search and rescue (S&R) methods consist of using signals in the visible spectrum to attract the attention of observers within overflying S&R aircraft. These existing methods have proven useful but have inherent limitations such as the requirement for daylight, good weather and relatively restricted areas of operations, due to aircraft range, observer fatigue and the field of view, due to the low altitudes required for a thorough search. The Canadian Forces Joint Imagery Centre (CFJIC), Advanced Exploitation Section (AES) and DRDC, Ottawa Research Centre conducted an imagery experiment at Connaught Range to define alternate methods of detecting downed aircrew using space-based sensors such as RADARSAT-2 and TerraSAR-X. Preliminary results demonstrate that the signal-to-noise ratio (SNR) of the target signature is significantly enhanced when the data are analyzed through phase-amplitude comparison of the synthetic aperture radar (SAR) image. These results suggest that the utility of exploiting the unique phase signature of a moving reflector and pendulum for S&R purposes can potentially be useful in designs for emergency gear.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g., Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Synthetic Aperture Radar, Micro-Doppler Analysis, Time-Frequency Analysis, Fourier Transform, Short-Time Fourier Transform, S-method, RADARSAT-2, TerraSAR-X